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<p>(51) International Patent Classification ⁷ : H01M 12/06, 12/02</p>	<p>A1</p>	<p>(11) International Publication Number: WO 00/38266 (43) International Publication Date: 29 June 2000 (29.06.00)</p>
<p>(21) International Application Number: PCT/US99/29721 (22) International Filing Date: 15 December 1999 (15.12.99) (30) Priority Data: 09/215,820 18 December 1998 (18.12.98) US (71) Applicant: AER ENERGY RESOURCES, INC. [US/US]; 4600 Highlands Parkway, Suite G, Smyrna, GA 30082 (US). (72) Inventors: TINKER, Lawrence, A.; 1106 Hunters Glen Drive, Woodstock, GA 30189 (US). BENTZ, R., Dennis; 804 Oak Trail Drive, Marietta, GA 30062 (US). (74) Agents: YOUNG, Jeffrey, E. et al.; Jones & Askew, LLP, 2400 Monarch Tower, 3424 Peachtree Road, N.E., Atlanta, GA 30326 (US).</p>		<p>(81) Designated States: CA, CN, JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</p>
<p>(54) Title: CYLINDRICAL METAL-AIR BATTERY WITH A CYLINDRICAL PERIPHERAL AIR CATHODE</p> <p>(57) Abstract</p> <p>A cylindrical metal-air cell has a cylindrical housing, an axially extending cylindrical air cathode adjacent an interior surface of the housing, and a plurality of elongate plenums defined between the oxygen electrode and the interior surface of the housing. Isolating passageways are positioned between the ambient environment and each of the plenums, and an air moving device is operable to force air through the isolating passageways and into at least one of the plenums. The air moving device may be a micromachined blower controlled by a circuit integrated into the housing of the blower.</p>		

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10 **CYLINDRICAL METAL-AIR BATTERY WITH A CYLINDRICAL PERIPHERAL
AIR CATHODE**

Related Applications

The following patent applications for related subject matter:

- 15 "AIR MANAGER SYSTEMS FOR METAL-AIR BATTERIES UTILIZING A
DIAPHRAGM OR BELLOWS" (Attorney Docket 01446-0890);
"AIR MOVER FOR A METAL-AIR BATTERY UTILIZING A VARIABLE VOLUME
ENCLOSURE" (Attorney Docket 01446-1110);
"DIFFUSION CONTROLLED AIR VENT WITH AN INTERIOR FAN" (Attorney
20 Docket 01446-0940);
"UNIFORM SHELL FOR A METAL-AIR BATTERY" (Attorney Docket 01446-1100);
"LOAD RESPONSIVE AIR DOOR FOR A METAL-AIR CELL" (Attorney Docket
01446-1130);
"Geometry Change Diffusion Tube For Metal-Air Batteries" (Attorney Docket 01446-
25 1000);
"AIR-MANAGING SYSTEM FOR METAL-AIR BATTERY USING RESEALABLE
SEPTUM" (Attorney Docket 01446-1070); and
"AIR DELIVERY SYSTEM WITH VOLUME-CHANGEABLE PLENUM OF METAL-
AIR BATTERY" (Attorney Docket 01446-0910);
30 all of which are incorporated herein by reference, have been filed concurrently with the present
application.

Technical Field

- 35 The present invention relates to metal-air batteries of the type that are supplied
with reactive gas by an active air moving device, and more particularly relates to a cylindrical
metal-air cell having a cylindrical peripheral air cathode.

Background of the Invention

Generally described, a metal-air cell, such as a zinc-air cell, uses one or more air permeable cathodes separated from a metallic zinc anode by an aqueous electrolyte. During operation of the cell, oxygen from the ambient air is converted at the one or more cathodes to produce hydroxide ions. The metallic zinc anode is then oxidized by the hydroxide ions. Water and electrons are released in this electrochemical reaction to provide electrical power.

Initially, metal-air cells found limited commercial use in devices, such as hearing aids, which required a low level of power. In these cells, the air openings which admitted air to the air cathode were so small that the cells could operate for some time without flooding or drying out as a result of the typical difference between the outside relative humidity and the water vapor pressure within the cell. However, the power output of such cells was too low to operate devices such as camcorders, cellular phones, or laptop computers. Furthermore, enlarging the air openings of a typical "button cell" was not practical because it would lead to premature failure as a result of flooding or drying out.

In order to increase the power output of metal-air cells so that they could be used to operate devices such as camcorders, cellular phones, or laptop computers, air managers were developed with a view to providing a flow of reactive air to the air cathodes of one or more metal-air cells while isolating the cells from environmental air and humidity when no output is required. As compared to conventional electrochemical power sources, metal-air cells containing air managers provide relatively high power output and long lifetime with relatively low weight. These advantages are due in part to the fact that metal-air cells utilize oxygen from the ambient air as the reactant in the electrochemical process as opposed to a heavier material such as a metal or a metallic composition. Examples of air managers are shown in U.S. Patents 4,913,983, 5,356,729, and 5,691,074.

Attempts have been made to design a metal-air cell to fit the form of a standard "D" or "AA" cylindrical alkaline cell. Cylindrical batteries without air managers are shown in U.S. Patent 3,697,326 and European Published Application No. 1,459,135. The lack of success of these designs likely is attributable to an inability to provide high enough power output for devices typically operated by conventional standard sized cylindrical cells without providing large air openings that allow the cells to flood or dry out.

Thus, there is a need in the art for a standard size cylindrical metal-air cell that can provide a power output level sufficient to operate electrical devices, whether individually or in groups inserted into a battery compartment of such devices. Such a cell also should not flood or dry out when inserted into such devices and left unattended during extended periods of non-use.

Summary of the Invention

The present invention seeks to provide a cylindrical metal-air cell that can provide a high power output level, and also can be inserted into electrical devices and left unattended during extended periods of non-use without flooding or drying out.

This object is achieved according to the present invention by a cylindrical metal-air cell having a generally cylindrical housing, a generally cylindrical oxygen electrode extending axially adjacent an interior surface of the housing, a plurality of elongate plenums defined between the oxygen electrode and the interior surface of the housing, an isolating passageway positioned between the ambient environment and each of the plenums, and an air moving device operable when on for forcing air through the isolating passageways and into at least one of the plenums. The isolating passageways are operable while unsealed and the air moving device is not forcing air through the isolating passageway to protect the cell from the ambient environment.

In one embodiment of the present invention, the axial plenums are formed by the shape of the electrode material, preferably a conductive, carbon-containing material. In this embodiment, the housing or case may be smoothly cylindrical. In another embodiment, the housing forms multiple axial plenums and the outer surface of the electrode material may be smoothly cylindrical. In either embodiment, the housing may be conductive, and the carbon material of the electrode may contact the housing to provide current collection for the electrode.

Preferably, the isolating passageways are formed in end pieces that seal the ends of the housing. The air moving device may be any appropriate apparatus for moving air, such as a miniature fan, a micromachine fan, or a diaphragm air pump. In an alternative embodiment of the invention, the isolating passageways may be provided only at one end of the housing and an air pathway may be defined so that air may be moved from that end along one set of the axial plenums in one direction along the cell, and returned along another set of the axial plenums in the opposite direction. Also, air may be forced into and out of a plenum through the same isolating passageway.

Cells embodying the present invention can be used individually, combined in a battery pack, or placed in groups in conventional battery compartments of electrical devices where the cells are connected in series or in parallel. Each cell having a standard "D" size can produce a power output of at least about 1.25 watt using a micromachine blower that draws 10% or less of the cell's available power while moving air at a rate of 75 cc per minute or higher. Each cell having a standard "AA" size can produce a power output of at least 0.5 watt using a micromachine fan that draws 10% or less of the cell's available power while moving air at a rate of 30 cc per minute or higher. It is possible to construct cells embodying the present invention having a standard "D" size that produce a power output of 2.5 watt or more using a

micromachine blower that draws 10% or less of the cell's available power while moving air at a rate of 150 cc per minute or higher, and cells having a standard "AA" size that produce a power output of 1.0 watt or more using a micromachine fan that draws 10% or less of the cell's available power while moving air at a rate of 60 cc per minute or higher. .

5 Other objects, features and advantages of the present invention will become apparent upon reviewing the following detailed description of preferred embodiments of the invention, when taken in conjunction with the drawings and the appended claims.

Brief Description of the Drawings

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Figure 1 is a side plan view of a cylindrical metal-air cell embodying the present invention.

Figure 2 is a side cross sectional view taken along line 2--2 of Fig. 1.

Figure 3 is an exploded pictorial view of the components of the cell of Figs. 1 and 2.

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Figure 4 is a radial cross sectional view taken along line 4--4 of Fig. 1.

Figure 5A is a radial cross sectional view taken along line 5--5 of Fig. 1 with the diaphragm and grid removed.

Figure 5B is a radial cross sectional view taken along line 5--5 of Fig. 1 with the grid in place.

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Figure 5C is a radial cross sectional view taken along line 5--5 of Fig. 1 with the grid and diaphragm in place.

Figure 6 is a diagrammatic exploded view of an alternative embodiment of a metal-air cell according to the present invention.

25 Figure 7 is an axial cross sectional view of the air cathode of the cell of Fig. 6, taken along line 7--7 of Fig. 8.

Figure 8 is a radial cross sectional view of the air cathode taken along line 8--8 of Fig. 7.

Figure 9 is a top view of a bottom sealing cup of the cell of Fig. 6.

Figure 10 is an axial cross sectional view taken along line 10--10 of Fig. 9.

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Figure 11 is an axial cross sectional view taken along line 11--11 of Fig. 9.

Figure 12 is an axial cross sectional view of the cell cap taken along line 12--12 of Fig. 6.

Figure 13 is a bottom plan view of the cell housing shown in Fig. 6.

Figure 14 is an axial cross sectional view of the cell of Fig. 6.

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Detailed Description

Referring now in more detail to the drawings, in which like numerals represent like parts throughout the several views, Fig. 1 shows a cylindrical metal-air cell 10 embodying the present invention. The cell 10 can be made in any desired size into which its components can be fit, such as a standard "D" or "AA" size.

As shown in Figs. 1-5, the cell 10 is built within a case or housing 12, which may be deep drawn from a conductive metal to form a can similar to those developed for other types of cells, such as alkaline cells. During the formation of the generally cylindrical housing 12, a plurality of spaced apart, axially extending indentations 50 are formed in the cylindrical wall 13 of the housing. The indentations 50 begin at a location spaced down from the top of the cell 10 and extend preferably the entire remaining length of the cylindrical wall. A protrusion 14 is formed in the bottom of the cell to act as a cathode terminal.

A hollow, cylindrical air cathode 18 is installed intermediate the length of the cell 10 with the top of the cathode approximately aligned just above the beginning of the indentations 50. The cathode may be made of a drilled out carbon-containing rod, or an extruded cylinder. The composition of the cathode preferably is a conductive carbon material such as carbon black, activated carbon, or graphitic type carbon, treated with a catalyst material to promote oxygen reduction, with a binder material such as Teflon or polyamide type polymer or other suitable polymer binder to provide mechanical strength. The exterior of the cathode could be coated with a hydrophobic material such as microporous Teflon to prevent liquid transfer but allow oxygen access to the carbon catalyst mixture. A suitable cathode composition is described in pending U.S. Patent Application No. _____, entitled "Primary Metal-Air Power Source and Ventilation System for the Same," filed October 23, 1998, and incorporated herein by reference.

A separator (a wettable microporous polypropylene sheet, not shown) lines the interior of the hollow cathode, which is filled with an anode material that preferably is a zinc powder gelled with an electrolyte solution, such as potassium hydroxide, in a known manner. A pair of non-conductive plates (not shown) hold the anode material within the center of the cathode. As shown in Fig. 4, the cathode 18 fits within the housing 12 in a manner so that a plurality of cathode plenums 20 are formed by the areas between the indentations 50 of the housing 12. The plenums 20 extend axially along the length of the cathode 18, and are spaced around its outer cylindrical surface.

Preferably, the conductive housing at the indentations 50 is in electrical contact with the cathode material, so that the housing itself may provide cathode current collection. In addition, copper foil strips 52 may be placed between the housing 12 and the cathode 18 at two indentations located on opposite sides of the housing. The strips 52 can be connected to the cathode terminal 14 to assist in current collection, and they also divide the plenums 20 into

two groups, which can define separate flow paths for air in a manner described below. If desired, the housing material at the indentations can be spaced away from the cathode material, leaving the copper foil strips 52 as the only cathode current collectors and allowing air to pass between the plenums within each group, but preferably not between the two groups. This alternative configuration increases the cathode surface exposed to the air for higher power output.

At the top of the cell 10, a sealing cap 202 is held in place closing off the open end of the cell 10 in a conventional manner using an annular crimped area 204 in the housing 12. The cap defines a central projection 205, that is somewhat smaller in diameter than the case 10 12. The projection 205 extends down to hold the cathode 18 and anode material 16 in place. An anode current collector spike 17 passes through the cap 202 at an opening 203 and extends axially down along the center of the anode material in a known manner. The upper end of the spike 17 provides an anode terminal.

The cap 202 defines a plurality of axially extending, peripheral isolating passageways 15 206 that remain unsealed when the cap 202 is otherwise sealed within the top of the cell. It should be understood that the passageways 206 optionally could be openings fully surrounded by cap material, or could connect the interior of the cell to the exterior environment along a different path, for example, to openings in the side wall of the housing 12.

20 Figs. 2 and 5 shows a retainer 22 that fits into the bottom of the cell housing 12. The retainer 22 holds the cathode 18 and anode 16 against the cap 202. The retainer is formed of a non-conductive material defining a hollow central core 23 and a plurality of projections 24 positioned to extend into the plenums 20 below the cathode 18. The projections are carefully shaped to seal off the plenums 20 with the exception of isolating passageways 25 left between 25 the projections 24 and the material of the housing 12, as shown in Fig. 5A. Mating openings 26 in the bottom of the housing allow air to enter each of the isolating passageways 25.

Within the hollow core 23 of the retainer 22, an air moving device 37 is mounted. The air moving device may be one of several types, for example a blower or a diaphragm air pump. In the embodiment of Figs. 1-5, the air moving device 37 includes a printed circuit board 30 (PCB) 42 on which is mounted a control circuit including a programmed processor and memory. The control circuit may, for example, contain an electrical load sensor, and operate the air moving device intermittently based on the demand of the load applied to the cell. Such operation is described in co-pending application serial number 08/936,206, filed September 24, 1997.

35 The air moving device also includes an electromagnetic oscillator made up of a coil 44 affixed to the upper side of the PCB 42, and a magnet 46 shaped to be received within a central opening in the coil 44. The magnet 46 is attached to a grid 47, to which is attached a diaphragm 48, which may be made of various flexible materials including a thermoplastic

elastomer (TPE) such as Santoprene® thermoplastic rubber available from Advanced Elastomer Systems. The grid 47 and the diaphragm 48 each have a circular center portion and defines tabs 49 and 51, respectively, extending radially into the plenums 20 of the housing 12 to fill the cross section of the housing 12. The periphery of the diaphragm 48, that is at least the tabs 49, is not attached to the grid 51. The diaphragm 48 thus is positioned between the isolating passageways 25 and the cathode plenums 20, and reciprocates with the magnet 46 when appropriate varying electrical current is supplied to the coil 44. When the magnet moves down, as viewed in Fig. 2, the diaphragm periphery separates from the plate 51 and allows air to pass from through the passageways 25, through the openings of the grid 47, around the diaphragm 48, and into a space created above the diaphragm. When the magnet moves up, the grid 51 carries the entire diaphragm up, compressing the air above the diaphragm and forcing it into the plenums 20. Thus, the diaphragm operates to pump air upward into the cathode plenums 20. The diaphragm 48 also could be driven by a piezoelectric oscillator or a microrelay.

In operation of the embodiment of Figs. 1-5, in response to a load being applied across the terminals 14 and 17, the control circuit on the PCB 42 supplies a varying current, powered by the cell itself, to the coil 44. The coil in turn causes the magnet 46 and attached diaphragm 48 to reciprocate, pumping air from outside the cell through the openings 26, upwardly through the isolating passageways 25, and through the cathode plenums 20, where the fresh air provides oxygen to facilitate the electrochemical reaction described above. The air then exits the cell through the isolating passageways 206. When the air moving device 37 is not operating, the isolating passageways 25 and 206 protect the cell components from flooding or drying out by restricting air flow into and out of the cell.

Alternatively, the isolating passageways 206 may be eliminated when the plenums 20 are divided into two groups by the foil strips 52 as described above. Ducts (not shown) may be installed to guide the air pumped by the diaphragm solely to the plenums 20 of one group, and a further duct (not shown) may be provided at the top of the cathode 18 connecting the two groups of plenums. According to this alternative arrangement, the air flows up the first group of plenums 20, across to the second group of plenums 20, down through the second group of plenums to the passageways 25 associated with the second group of plenums, and out of the cell.

While power is being drawn from the cell 10, the circuit connecting the anode 16 and the cathode 18 extends from the anode spike 17, through the applied load, the cathode terminal 14, the conductive housing 12, and the cathode material 18 at the indentations 50. A nonconductive film (not shown) may be used to cover the cylindrical wall portion of the housing 12.

A second embodiment of the present invention in a cell 100 is shown in Figs. 6-14. Those components bearing the same reference numerals have the same structure and function

as described above in connection with the earlier embodiment. The cell 100 is built within a cylindrical case or housing 112, which has a generally smooth cylindrical wall 113. At the bottom of the housing 112, a projection 114 is formed to serve as a cathode terminal, and a plurality of air openings 109 pass through the bottom of the housing to allow outside air to enter the cell 100. A nonconductive layer 110, such as a plastic film, is attached to the cylindrical wall 113, as shown in Fig. 13.

Referring to Figs. 7-10, a hollow cathode 118 fits into the housing 112 and contacts the inner surface of the housing. In contrast to the smooth outer surface of the cathode 18 described above, the cathode 118 is formed or extruded with peripheral, axial grooves 120, defined between elongate ridges 150. The ridges 150 contact the conductive housing 112 for cathode current collection, and thus cathode plenums are formed by the grooves 120 bounded by the housing 112. At the lower end of the cathode 118 is an area without ridges 150, defining a cathode extension 151. The preferred composition of the cathode 118 is as described above.

The cathode 118 is glued into a cup-shaped retainer 200 as shown in Fig. 14. The retainer 200, shown in detail in Figs. 9-11, defines an upper recess 211 for receiving the cathode extension 151. A plurality of isolating passageways 204 are formed in the outer circumference of the retainer 200, separating ridges 152. The passageways 204 align with the axial grooves 120. A lower recess 214 is also formed in the retainer 200 for receiving an air mover assembly 137 described below. The lower recess communicates with a lower end of each of the passageways 204.

As was the case with the first embodiment described above, anode material 16 fills the hollow portion of the cathode 118. A cap 202 carrying a current collector spike 17 and defining isolating passageways 206 is installed at the top of the housing 112 in the manner described above. The anode material 16 is retained between the cup retainer 200 and the cap 202.

The air mover assembly 137 shown in cross section in Figs. 6 and 14 is a micromachine of the type based on the micromachining of non-metallic materials such as silicon carbide, using lithography to define planar geometries which are then formed into structures by etching or vapor deposition. Multiple layers are employed to create complex three-dimensional devices. A description of rotary micromachine devices may be found in Epstein, A.H. et al., "Micro-Heat Engines, Gas Turbines, and Rocket Engines - The MIT Microengine Project," 28th AIAA Fluid Dynamics Conference/4th AIAA Shear Flow Control Conference (American Institute of Aeronautics and Astronautics, No. AIAA 97-1773, June 29-July 2, 1997). A description of a micromotor may be found in U.S. Patent 4,943,750 to Howe et al. The diagrammatic representation of the air moving device in Figs. 6 and 14 is greatly exaggerated.

Using these micromachining techniques, a blower housing 138 is fabricated enclosing a motor 140 and a squirrel cage blower 142 mounted on the motor drive shaft. The motor 140 may be of the type shown in U.S. Patent 4,943,750, which is incorporated herein by reference in its entirety. The motor draws about 30 milliwatts from the cell to operate. The blower
5 rotates on an air bearing at supersonic peripheral speeds. The diameter of the blower 142 may be, for example, 4 mm to 20 mm. The thickness of the housing 138 may be, for example, a few hundred microns. An inlet opening 145 communicates with the interior of the housing 112 in a lower portion adjacent to the air openings 109. One or more outlet openings 146 allow the blower to force air through the isolating passageways 204 into the cathode plenums
10 120. Preferably, there is an outlet 146 aligned with each plenum 120. After traversing the plenums 120, the air may escape the cell through the isolating passageways 206.

The motor/blower 140, 142 operates at very high rotational speed, for example, 2 million rpm or more. At such high rpm, acoustic noise is at a low level at which persons using devices powered by the cell either would not be inconvenienced by the noise, or would not
15 notice any noise.

When fabricating the blower using semiconductor manufacturing techniques, a control circuit is incorporated in the structure of the blower housing 138. This integrated circuit may be programmed to perform similar functions to those carried out by the circuit of the PCB 42 described above. In particular, the air moving device 137 may be operated in a pulsed manner
20 to preserve energy. Thus, the air moving device 137 unifies the blower, motor, and control electronics in one device that occupies very little space, draws power at a low rate, and can be manufactured inexpensively using semiconductor mass production techniques.

As noted above, each cell having a standard "D" size can produce a power output of at least about 1.25 watt using a micromachine blower that draws 10% or less of the cell's
25 available power while moving air at a rate of 75 cc per minute or higher. Each cell having a standard "AA" size can produce a power output of at least 0.5 watt using a micromachine fan that draws 10% or less of the cell's available power while moving air at a rate of 30 cc per minute or higher. It is possible to construct cells embodying the present invention having a standard "D" size that produce a power output of 2.5 watt or more using a micromachine
30 blower that draws 10% or less of the cell's available power while moving air at a rate of 150 cc per minute or higher, and cells having a standard "AA" size that produce a power output of 1.0 watt or more using a micromachine fan that draws 10% or less of the cell's available power while moving air at a rate of 60 cc per minute or higher..

Referring in detail to the isolating passageways described above, these isolating
35 passageways are preferably constructed and arranged to allow a sufficient amount of airflow therethrough while the air moving device is operating so that a sufficient output current, typically at least 50 ma, and preferably at least 130 ma can be obtained from the metal-air cells. In addition, the isolating passageways are preferably constructed to limit the airflow and

diffusion therethrough such that the drain current that the metal-air cells are capable of providing to a load while the air moving device is not forcing airflow through the isolating passageways is smaller than the output current by a factor of about 50 or greater. In addition, the isolating passageways are preferably constructed to provide an "isolation ratio" of more than 50 to 1.

The "isolation ratio" is the ratio of the rate of water loss or gain by a cell while its oxygen electrodes are fully exposed to the ambient air, as compared to the rate of the water loss or gain of the cell while its oxygen electrodes are isolated from the ambient air, except through one or more limited openings. For example, given identical metal-air cells having electrolyte solutions of approximately thirty-five percent (35%) KOH in water, an internal relative humidity of approximately fifty percent (50%), the ambient air having a relative humidity of approximately ten percent (10%), and no fan-forced circulation, the water loss from a cell having an oxygen electrode fully exposed to the ambient air should be more than 100 times greater than the water loss from a cell having an oxygen electrode that is isolated from the ambient air, except through one or more isolating passageways of the type described above. In this example, an isolation ratio of more than 100 to 1 should be obtained.

More specifically, each of the isolating passageways preferably has a width that is generally perpendicular to the direction of flow therethrough, and a length that is generally parallel to the direction of flow therethrough. The length and the width are selected to substantially eliminate airflow and diffusion through the isolating passageways while the air moving device is not forcing airflow through the isolating passageways. The length is greater than the width, and more preferably the length is greater than about twice the width. The use of larger ratios between length and width are preferred. Depending upon the nature of the metal-air cells, the ratio can be more than 200 to 1. However, the preferred ratio of length to width is about 10 to 1.

The isolating passageways could form only a portion of the path air must take between the ambient environment and the oxygen electrodes. Each of the isolating passageways may be defined through the thickness of the battery housing or cell case, but preferably they are in the form of tubes as described above. In either case, the isolating passageways may be cylindrical, and for some applications each can have a length of about 0.3 to 2.5 inches or longer, with about 0.88 to 1.0 inches preferred, and an inside diameter of about 0.03 to 0.3 inches, with about 0.09 to 0.19 inches preferred. The total open area of each isolating passageway for such applications, measured perpendicular to the direction of flow therethrough, is therefore about 0.0007 to 0.5 square inches. In other applications, such as small cylindrical cells, the isolating passageways each can have a length of about 0.1 to 0.3 inches or longer, with about 0.1 to 0.2 inches preferred, and an inside diameter of about 0.01 to 0.05 inches, with about 0.015 inches preferred. The preferred dimensions for a particular

application will be related to the geometry of the passageways and the cathode plenums, the particular air mover utilized, and the volume of air needed to operate the cells at a desired level.

5 The isolating passageways are not necessarily cylindrical, as any cross-sectional shape that provides the desired isolation is suitable. The isolating passageways need not be uniform along their length, so long as at least a portion of each isolating passageway is operative to provided the desired isolation. Further, the isolating passageways may be straight or curved along their length.

10 Other exemplary isolating passageways and systems are disclosed in U.S. Patent No. 5,691,074 and U.S. Application No. 08/556,613, and the entire disclosure of each of those documents is incorporated herein by reference.

15 Those skilled in the art will appreciate that other types of air moving devices could be used in the embodiments of the invention described above. For example, various types of rotary fans, piezoelectric air pumps, peristaltic air pumps, collapsible chamber air pumps, and other air movers could be used. Air moving devices are shown in the "Related Applications" listed above, which are incorporated herein by reference in their entireties.

Claims

1. A metal-air power supply, comprising:
 - a generally cylindrical housing having opposite ends and defining a length and
 - 5 an axial direction between the opposite ends;
 - an axially extending oxygen electrode adjacent an interior surface of the housing;
 - a plurality of elongate plenums defined between the oxygen electrode and the interior surface of the housing;
 - 10 a plurality of isolating passageways that at least partially define a communication path between the ambient environment and each of the plenums; and
 - an air moving device operable when on for forcing air through the isolating passageways and into the plenums, the isolating passageways being operable while unsealed and the air moving device is not forcing air through the isolating passageways to restrict
 - 15 airflow through the isolating passageways.
2. The metal-air power supply of claim 1, further comprising:
 - an anode surrounded by the oxygen electrode; and
 - a cap covering a first end of the oxygen electrode to contain the anode within
 - 20 the oxygen electrode; and
 - wherein the isolating passageways are defined between the cap and the interior surface of the housing.
3. The metal-air power supply of claim 2, wherein the cap is positioned between
- 25 the air moving device and the oxygen electrode.
4. The metal-air power supply of claim 1, wherein:
 - the plurality of isolating passageways is a plurality of first isolating passageways;
 - 30 the metal-air power supply further comprises a plurality of second isolating passageways proximate to a second end of the oxygen electrode and each of which at least partially defines a communication path between the ambient environment and at least one of the plenums.
- 35 5. The metal-air power supply of claim 5, wherein said first and second isolating passageways collectively provide an isolation ratio of at least 100 to 1.

6. The metal-air power supply of claim 1, wherein said passageways are formed by elongate recesses in said oxygen electrode.

7. The metal-air power supply of claim 1, wherein said passageways are formed by elongate indentations in said housing.

8. In a metal-air cell including an air electrode positioned within a housing, an air manager comprising:

an air pathway defined within said housing and extending adjacent to said air electrode;

an inlet and an outlet at each end of said pathway communicating with an environment outside said housing; and

a micromachine blower mounted to force air through said air pathway;

said cell generating a power output of 0.5 watt or more when said micromachine blower is operating, and said blower drawing no more than 10 % of the cell's available power while moving air at a rate of 30 cc per minute or higher.

9. The metal-air cell of claim 8, wherein said cell is generally cylindrical and said air pathway includes a plurality of elongate cathode plenums extending axially between said housing and a generally cylindrical cathode inserted within said housing.

10. The metal-air cell of claim 8, , further comprising a control circuit integrated into a micromachined enclosure of said micromachine blower, said control circuit controlling the operation of said blower; and wherein said cell generates a power output of 1.25 watts or more when said micromachine blower is operating, and said blower draws no more than 10% of the cell's available power while moving air at a rate of about 75 cc per minute or higher.

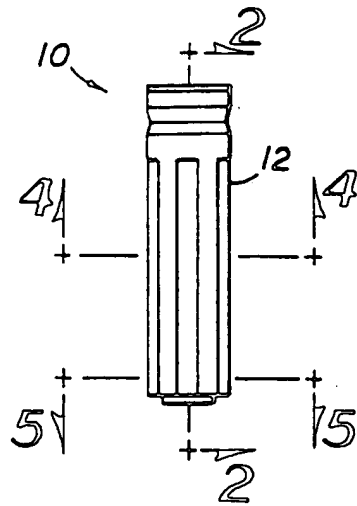


FIG 1

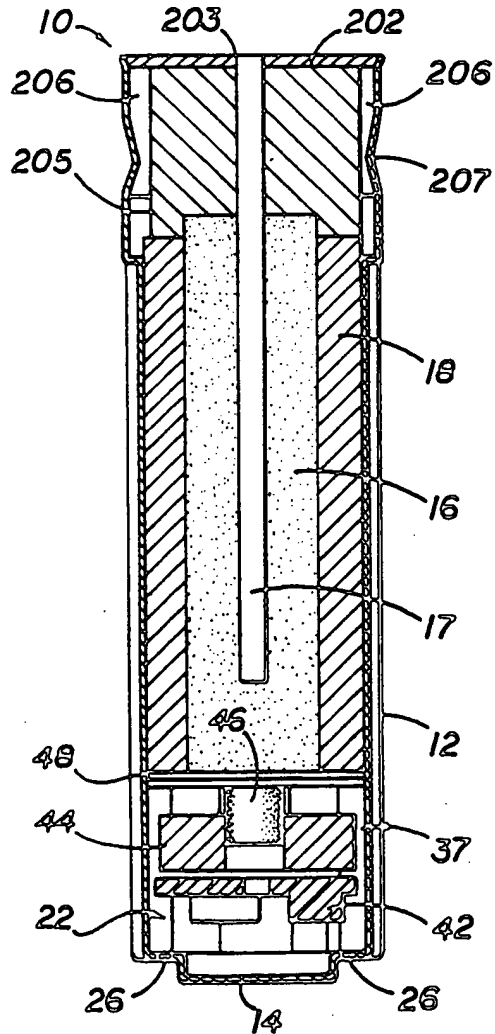


FIG 2

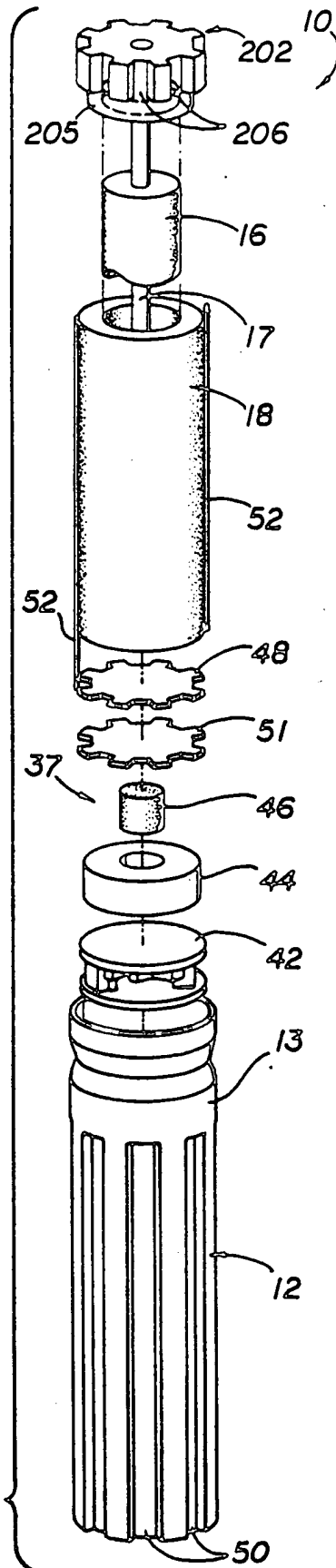


FIG 3

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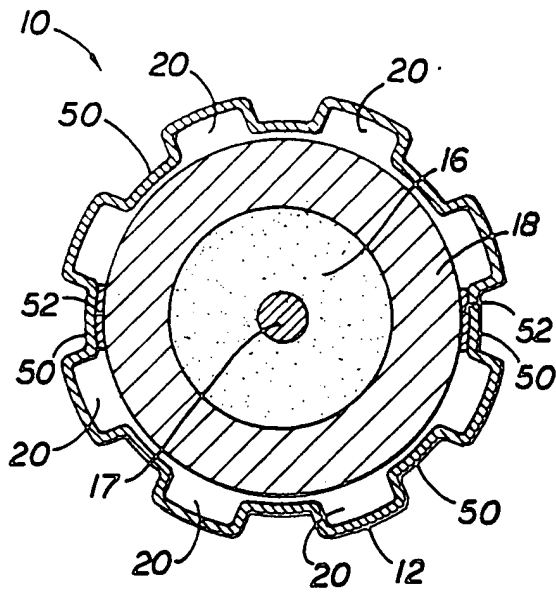


FIG 4

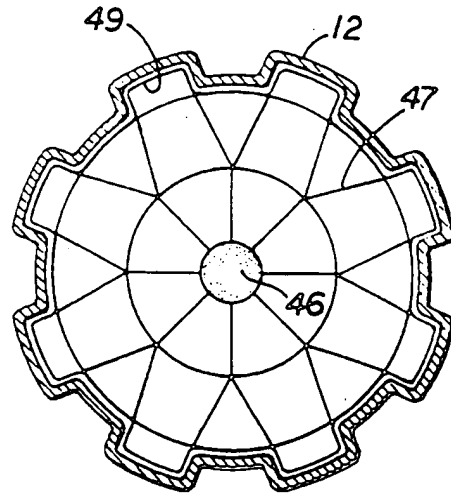


FIG 5B

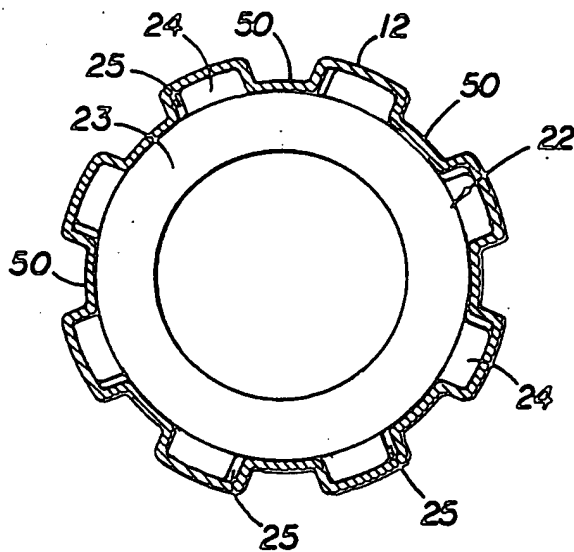


FIG 5A

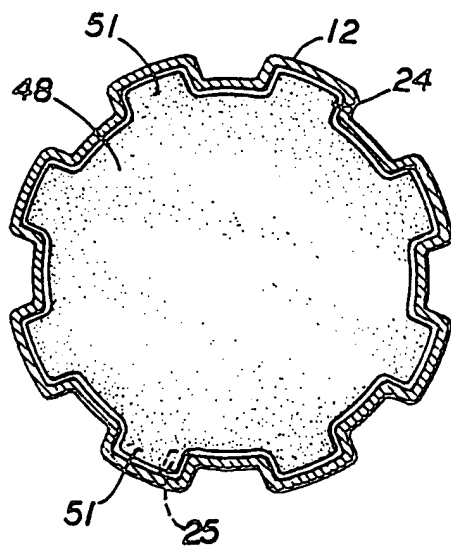
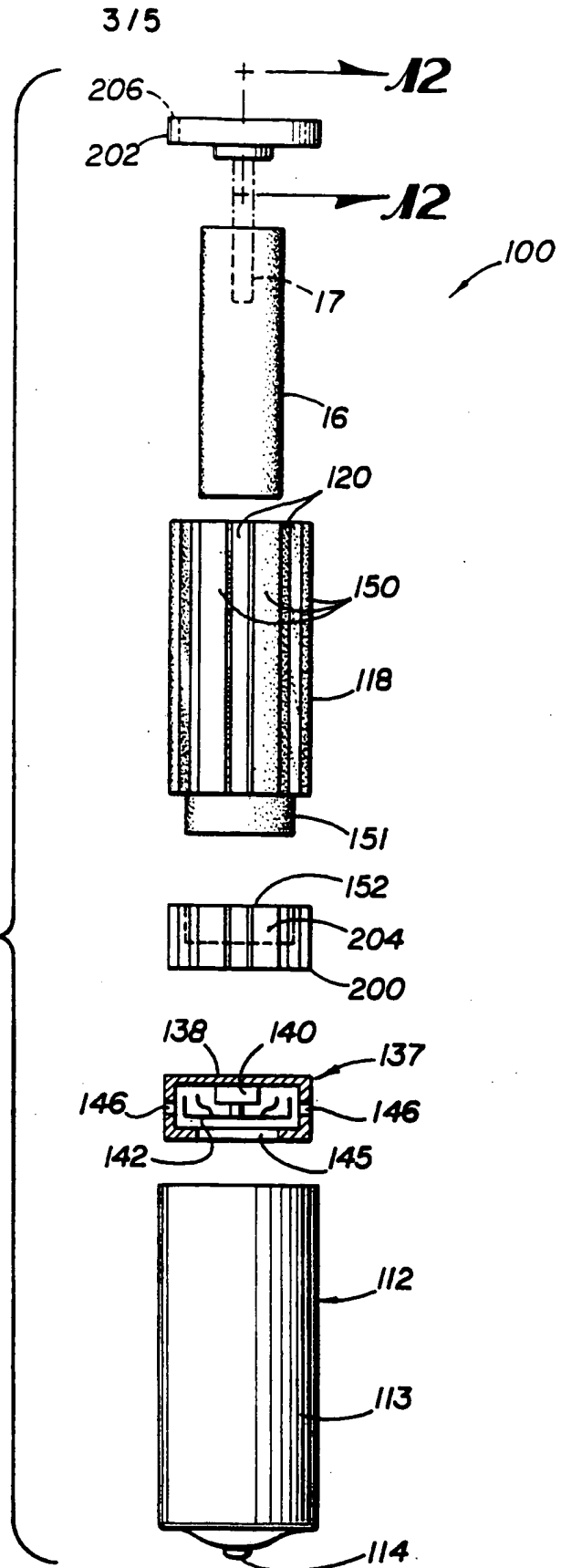


FIG 5C

FIG 6



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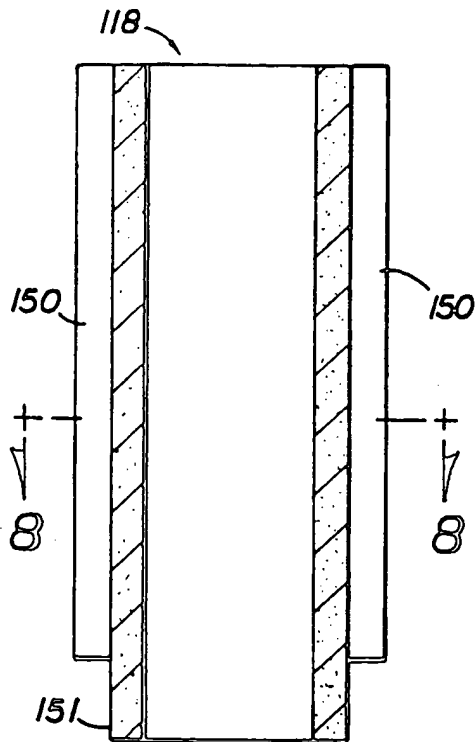


FIG 7

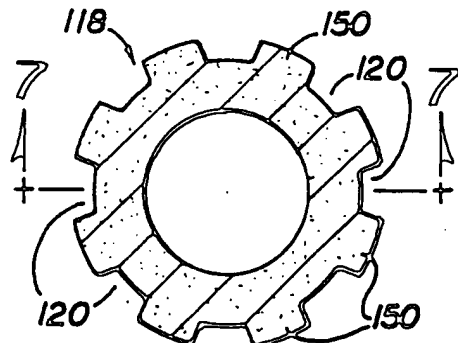


FIG 8

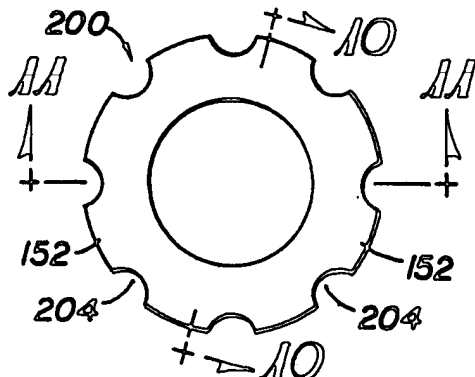


FIG 9

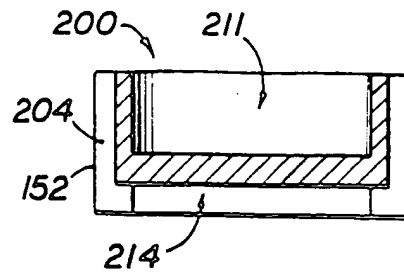


FIG 11

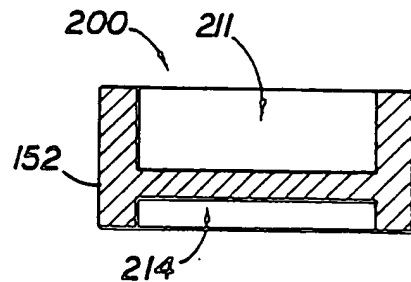


FIG 10

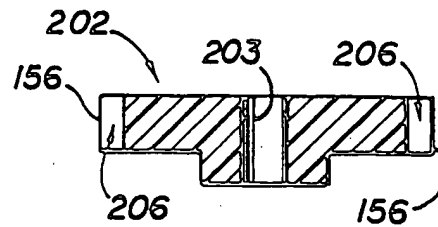


FIG 12

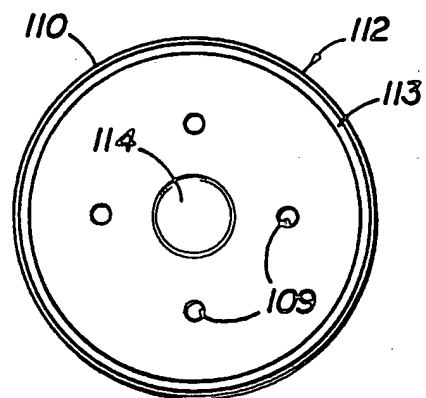
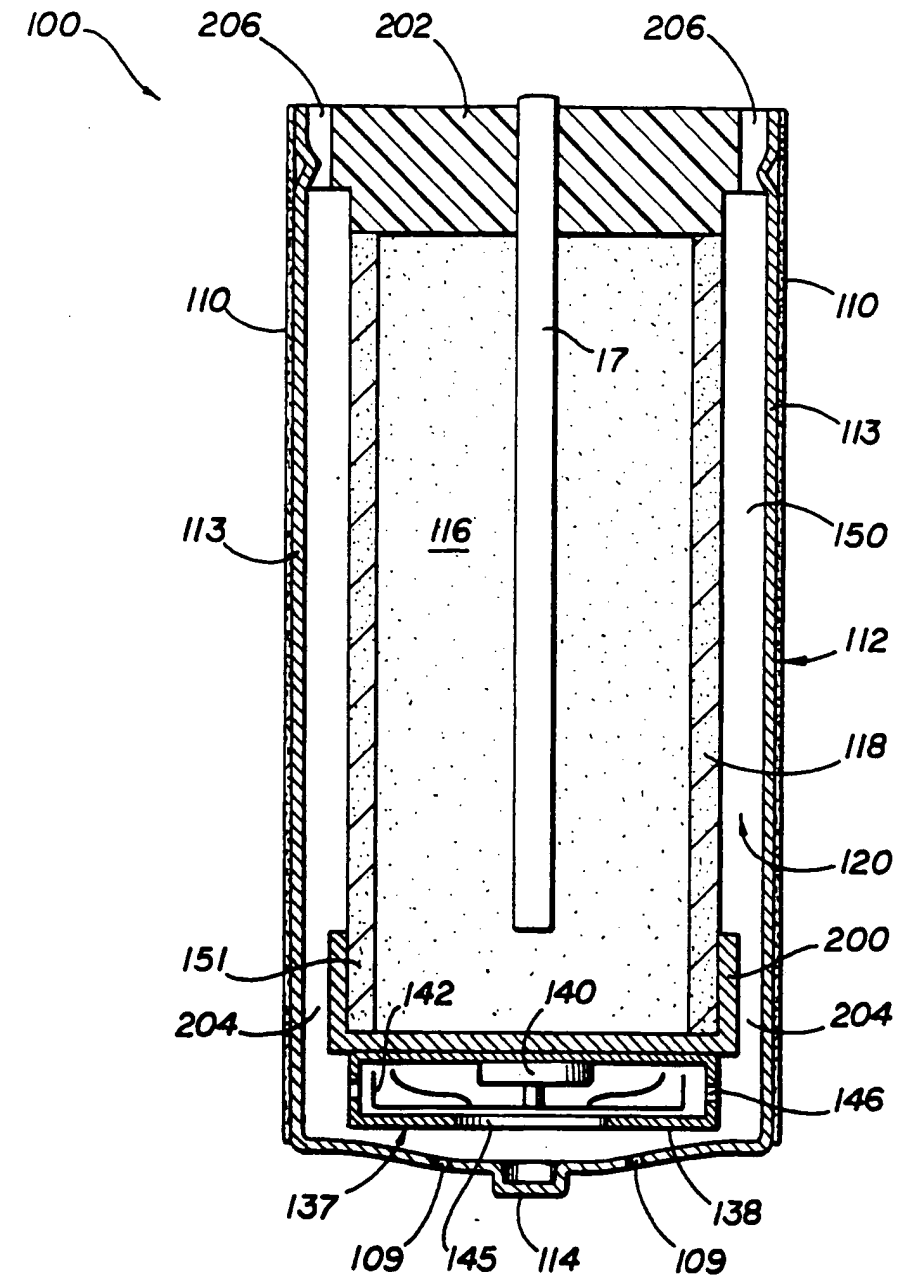


FIG 13

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**FIG 14**

INTERNATIONAL SEARCH REPORT

Intern. Appl. No.

PCT/US 99/29721

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01M12/06 H01M12/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01M

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 258 239 A (KOBAYASHI KAZUO) 2 November 1993 (1993-11-02) the whole document	1-10
A	US 5 354 625 A (BENTZ R DENNIS ET AL) 11 October 1994 (1994-10-11) the whole document	1-10
A	US 4 943 750 A (SCHLECHT MARTIN F ET AL) 24 July 1990 (1990-07-24) cited in the application column 3, line 54-64	8-10
A	US 4 913 983 A (CHEIKY MICHAEL C) 3 April 1990 (1990-04-03) cited in the application the whole document	1-10

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☒ Further documents are listed in the continuation of box C.

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Date of the actual completion of the international search

13 April 2000

Date of mailing of the international search report

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A	GB 1 317 214 A (HITACHI MAXELL) 16 May 1973 (1973-05-16) the whole document	1-10

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intcr. and Application No

PCT/US 99/29721

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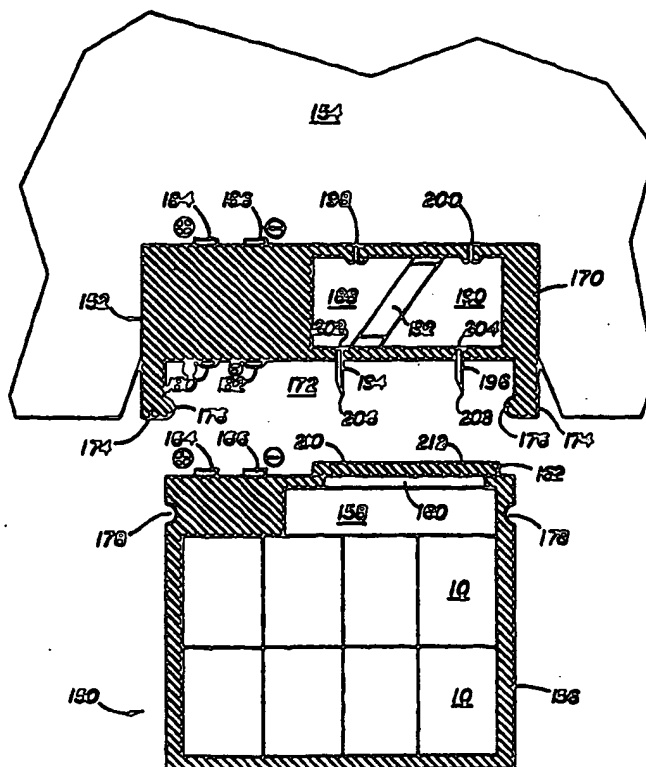
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁷ : H01M 12/06, 2/10		A1	(11) International Publication Number: WO 00/36699
			(43) International Publication Date: 22 June 2000 (22.06.00)
(21) International Application Number: PCT/US99/30382		(81) Designated States: CA, CN, JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).	
(22) International Filing Date: 20 December 1999 (20.12.99)			
(30) Priority Data: 09/216,343 18 December 1998 (18.12.98) US 09/321,352 27 May 1999 (27.05.99) US		Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	
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(72) Inventors: PEDICINI, Christopher, S.; 405 Saddlebrook Drive, Roswell, GA 30075 (US). WITZIGREUTER, John, D.; 4157 Springhill Lane, Kennesaw, GA 30144 (US).			
(74) Agents: YOUNG, Jeffrey, E. et al.; Jones & Askew, LLP, 2400 Monarch Tower, 3424 Peachtree Road, N.E., Atlanta, GA 30326 (US).			

(54) Title: AIR-MANAGING SYSTEM FOR METAL-AIR BATTERY USING RESEALABLE SEPTUM

(57) Abstract

An air-managing system for metal-air battery includes resealable septum and one or more hollow needles. The septum separates air pathway into two segments. One segment is from air cathodes of the battery to the septum and the other is from the septum to the outside air. The needles provide conduits to connect two segments. The septum re-closes its torn portion when the needles are removed. Also disclosed is a reusable air manager including a fan and such needles. The air manager can be coupled to a disposable cell pack which has a septum that can be pierced by the needles.



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**AIR-MANAGING SYSTEM FOR METAL-AIR BATTERY
USING RESEALABLE SEPTUM**

15 **Cross-Reference to Related Applications**

The following patent applications, all of which are incorporated herein by reference, contain related subject matter and are being filed concurrently with the present application.

20 "CYLINDRICAL METAL-AIR BATTERY WITH A
CYLINDRICAL PERIPHERAL AIR CATHODE"(Attorney Docket 01446-0805);

"AIR MANAGER SYSTEMS FOR METAL-AIR BATTERIES
UTILIZING A DIAPHRAGM OR BELLOWS" (Attorney Docket 01446-0890);

25 "AIR MOVER FOR A METAL-AIR BATTERY UTILIZING A
VARIABLE VOLUME ENCLOSURE" (Attorney Docket 01446-1110);

"DIFFUSION CONTROLLED AIR VENT WITH AN INTERIOR
FAN" (Attorney Docket 01446-0940);

"UNIFORM SHELL FOR A METAL-AIR BATTERY"(Attorney
Docket 01446-1100);

30 "LOAD RESPONSIVE AIR DOOR FOR A METAL-AIR CELL"
(Attorney Docket 01446-1130);

"GEOMETRY CHANGE DIFFUSION TUBE FOR METAL-AIR BATTERIES" (Attorney Docket 01446-1000); and

"AIR DELIVERY SYSTEM WITH VOLUME-CHANGEABLE PLENUM OF METAL-AIR BATTERY" (Attorney Docket 01446-0910).

5

Field of the Invention

The present invention relates generally to batteries, and more particularly relates to an air-managing system for a metal-air battery.

10

Description of the Related Art

Metal-air battery cells include an air permeable cathode and a metallic anode separated by an aqueous electrolyte. During discharge of a metal-air battery, such as a zinc-air battery, oxygen from the ambient air is converted at the cathode to hydroxide, zinc is oxidized at the anode by the hydroxide, and water and electrons are released to provide electrical energy. Metal-air batteries have a relatively high energy density because the cathode utilizes oxygen from ambient air as a reactant in the electrochemical reaction rather than a heavier material such as a metal or metallic composition. Metal-air battery cells are often arranged in multiple cell packs within a common housing to provide a sufficient amount of power output. The result is a relatively lightweight battery.

20

To operate a metal-air battery cell, it is necessary therefore to provide a supply of oxygen to the air cathodes of the cells. An air manager system is typically used to provide reactive air and to isolate the air cathodes when the cell is idle. Some prior systems open air cathodes widely to the atmosphere or use a fan system to sweep a flow of new ambient air from openings across the air cathodes to supply oxygen at a rate sufficient to achieve the desired power output. The open air cathodes or the openings are generally sealed during non-use by sealing tapes, plugs, mechanical doors, etc. because the water vapor and oxygen in the ambient air would cause the cell to flood, dry out, or discharge in some circumstances, thereby leading to a reduction in cell efficiency and lifetime. Diffusion-controlling openings have been applied to the air manager, as shown in U.S. Patent

25

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5,691,074. However, a more strict isolation may sometimes be desired for a longer shelf life.

5 The above-described sealing systems such as a sealing-tape are generally designed for single use and require new sealing means such as a new tape to seal the opening again. Mechanical doors are usually durable and thereby can open and close the openings more than once. The doors typically are positioned on a battery housing case such that a disposable battery body may have door mechanisms, which may be reusable even after the battery loses its power. However, the mechanisms require expensive moving parts and they tend to leak.

10 Thus, there has been a need for a reusable and practical sealing system to prevent water vapor transfer and leakage current when the battery is not in use. The system should be simple and work repeatedly during a battery lifetime, and further minimize disposable parts to lower the cost and to protect the environment. Along these lines, it would be efficient not to have to dispose of an
15 air manager when every cell pack reaches the end of its useful life. If the battery could be divided into a disposable part and a reusable part, a simple and reliable engaging means to connect two parts may be needed.

Summary of the Invention

20 The invention seeks to provide an improved ventilation system and an improved ventilating method for a metal-air cell or battery, which has a long shelf life and retains essentially all its original power during a period of storage.

In accordance with the invention, this object is accomplished in a metal-air power supply system having two air pathway segments separated by a
25 self-sealable septum, and a hollow needle to puncture the septum.

The present invention, therefore, provides a ventilation system for a metal-air battery having a housing or a case for enclosing at least one metal-air cell, at least one self-sealable septum, and one or more hollow needles. The case has at least one opening that is covered with the self-sealable septum and is sealed off
30 from a reactive gas source or the outside air. Thus, the septum divides an air pathway into two segments. The first segment from an air cathode of the cell is

enclosed in the case and terminated by the septum. The second segment to the outside air includes tubular passages of the hollow needles. When the needles penetrate the septum, the two segments are connected and the air pathway is completed to convey a reactive gas, e.g., oxygen, to the air cathode from the outside air.

The present invention provides a multi mode ventilation system for a metal-air battery with one or more openings connected to the outside air in the second segment. At least one air-moving device is disposed in the second segment such that the device may give a satisfactory air flow rate for required power. If the openings are preferably sized, leakage current of the cell may be lowered for non-use conditions when the air-moving device is off. Furthermore, the preferably sized openings prevent the cell from flooding and drying out by exchanging water vapor with the outside air. Thus, the lowest mode is for storage, a middle mode is for non-use, and the highest mode is to provide power with the air-moving device on.

The present invention further provides a power supply system having a cell pack with at least a self-sealable septum and an air-managing device with one or more hollow needles. The cell pack may be stored alone to maintain the original power. The air-managing device engages with the cell pack when the power supply is needed.

The present invention further provides an electric device with an air-managing device and a disposable cell pack with a self-sealable septum. The air-managing device is combined in the electric device such that the consumers may only have to buy a disposable cell pack.

The present invention further provides a cell pack including one or more metal-air cells in a housing which has air opening sealed by resealable septum.

The present invention further provides a reusable ventilation system that engages with an above-mentioned cell pack. The ventilation system has one or more hollow needles, at least one air moving device or fan, and one or more openings for air ingress and egress.

Other features and advantages of the present invention will become apparent upon reviewing the following description of preferred embodiments of the invention, when taken in conjunction with the drawings and the appended claims.

5 **Brief Description of the Drawing**

FIG. 1 is a diagrammatic top view of the cell pack case and the hollow needle embodying the present invention showing position of the cells, the opening, the septum, and the hollow needle, indicating the movement direction of the needle to engage the case.

10 FIG. 2 is a vertical cross sectional view taken along line 2--2 of FIG.1, showing the needle ready to pierce the septum the case.

FIG. 3 is a vertical cross sectional view of the cell pack case engaged by the hollow needle.

15 FIG. 4 is a diagrammatic perspective view of a second embodiment of the present invention showing a cell pack including a septum positioned adjacent to an air manager equipped with hollow needles.

FIG. 5 is a vertical cross sectional view taken along line 5--5 of FIG.4.

20 FIG. 6 is a diagrammatic top view of a cell pack adjacent to an air manager of a third embodiment of the present invention.

FIG. 7 is a diagrammatic top view of a cell pack incorporating an air-moving device, and adjacent to a puncturing device of a fourth embodiment of the present invention.

25 FIG. 8 is a diagrammatic top view of a cell pack and an air-moving device contained in an electric device according to a fifth embodiment of the present.

FIG. 9 is a perspective view of a metal-air battery or a power supply according to a sixth embodiment of the present invention.

30 FIG. 10 is a vertical cross sectional view taken along line 10--10 of FIG.9.

FIG. 11 is a vertical cross sectional view taken along line 11--11 of FIG. 9.

Description of the Preferred Embodiment

5 Referring now in more detail to the drawings, in which like numerals refer to like parts throughout the several views, FIGS 1, 2, and 3 show one embodiment of the present invention. This embodiment is suitable for continuous operation of the cells to provide power and to provide sufficient oxygen to generate the power without a fan. The metal-air battery includes a plurality of
10 cells 10 enclosed within a cell case 12. Since the present invention applies to primary and secondary metal-air cells, the cells of the first embodiment and the following embodiments are similar to those disclosed and known. Suitable components for primary metal-air cells are described in U.S. Patents 5,721,065. Secondary cells also can be used with or without an air mover embodying the
15 present invention, such as that described in U.S. Patent 5,569,551. All types of metal-air cells may benefit by use of the present invention. The figures are exaggerated for illustration. Although the use of the invention with a zinc-air battery is disclosed, this invention should be understood as being applicable to other types of metal-air battery cells. The present invention can be used with
20 primary or secondary batteries.

The case 12 isolates the plurality of cells 10 from the outside air and defines an opening 14 that is covered with a self-sealable septum 16. The cells 10 are generally arranged such that a reactant air plenum 18 is positioned under the
25 cells 10. The air plenum 18 generally defines an air pathway to air cathodes of the cells 10. The septum 16 is affixed at a lower portion of the case 12 and terminates the air pathway at the opening 14. A cell pack 20 includes the cells 10, the plenum 18, the case 12, and the septum 16. The cell pack 20 does not have any air vents.

A hollow needle 22 is positioned so as to puncture the septum 16. The needle 22 may be supported by a board, a case, or the like such that reciprocal
30 longitudinal motion of the needle is enabled. The needle 22 has a needle tip 24, a longitudinal tubular passage 26, and a circular cylindrical wall defining the passage.

The needle 22 is preferably aligned perpendicular to the septum 16 so that a longitudinal motion of the needle 22 toward the septum 16 allows the needle tip 24 to pierce a portion 28 of the septum 16 and the septum material to surround tightly outside of the needle wall for sealing (FIG. 3). Part of the length of the needle 22 is inserted through the septum 16 and the needle is held by the septum material around the needle 22. Thus, the longitudinal tubular passage 26 provides an air pathway to the outside air.

By a longitudinal reverse motion of the inserted needle 22 (FIG. 3), the needle 22 is removed and the septum 16 re-closes and reseals the torn portion 28 to seal off the cell pack 20 from the outside air. This mechanism is similar to that of a vaccine bottle septum from which an inserted hypodermic needle is removed. The needle 22 may be repeatedly re-inserted through the septum 16 and removed from the septum 16 again.

The cell pack 20 may be stored before use or when the cells 10 are inactive. Because the cells 10 are not exposed to fresh air and because leakage current may be minimized, they tend to have a longer shelf life than any cell enclosed by a housing with air vents. When the cell pack 20 is in use or when the cells 10 are active, the hollow needle 22 punctures the septum 16 and the longitudinal tubular passage 26 provides an air pathway to the outside air as described before. Thus, the cells 10 supply enough current to power a load. The present invention, therefore, enables the cells to have a long shelf life and to supply enough power from time to time without using any complicated mechanical doors or any single-use tapes.

The longitudinal tubular passage or hollow portion 26 of the needle 22 is sized to satisfy a load power requirement for oxygen while it limits an air flow rate from the outside air. Thus, the tubular passage diameter may be constructed to allow the air flow. If the needle 22 is too thin, the tubular passage may allow too little air flow. If the needle 22 is too big, it may not be easy for the septum 16 to re-close the tubular passage. If the length is shorter than 1/8", it is difficult for the needle to puncture the septum 16 and/or the tube may not be able to limit the air

flow rate to a desired maximum. If the length is longer than 1/2", it is difficult to handle the needle 22 and to puncture the septum 16 with the needle 22.

Any number of the longitudinal tubular passages 26, that is, any number of needles can be used to satisfy power requirement though FIG.1 shows single needle. Two or more needles may be preferable because one or more inlet and outlet tubular passages may be supplied. By way of example, if the same power as mentioned above is required for the cell pack 20 with two needles, each needle may have a tubular passage from 0.05 to 0.25 square inches in cross-sectional area and from 0.2 to 0.5 inches in length.

The case material is mechanically self-supporting and may be plastic, metal, ceramics, or another generally gas-impermeable material. Some gas permeability through a plastic housing can be tolerated. Materials inert to acid or base may be preferable since most electrolytes are acid or base. The septum 16 is typically made of rubber, a synthetic elastomer, or known compounds that give self-resealing characteristics to the septum 16. Suitable septum material includes that used to protect medicines in vials, such as silicone, PTFE/silicone, natural rubber, butyl rubber, PTFE/natural rubber, PTFE/butyl rubber, fluorocarbon rubber, Viton[®] etc. These materials are usually gas-impermeable, or hardly have permeability to water, which makes the cell pack well isolated from the outside air or any other reactive gas source and gives it a long shelf life. Further, low permeability prevents a high or low concentration of water vapor in the outside air from flooding or drying out the cells 10.

However, if it is preferable to have a high initial open cell voltage and to prevent consumers from finding that a new cell pack shows a very low voltage, a semi-permeable material may be employed. The semi-permeable material can pass oxygen or a reactive gas so as to keep an open cell voltage of the cells 10 high enough for immediate use. The septum material in this case is typically chosen from silicone rubber or resin, and other oxygen semi-permeable materials.

By way of example, if a typical silicone rubber that has an oxygen permeability coefficient of 19685 ($\text{cm}^3\text{-mm/m}^2\text{ day atm}$) is used for the cell pack 20 with an open area of 6 cm^2 , and if the required leakage current is about 1 ma, then

the required oxygen flow rate is 5.47 cm³/day at 25° Celsius. Thus, the thickness of the septum t may be given by

$$t = 19685 \times 6 \times 10^{-4} \times 0.21 / 5.47 = 0.45 \text{ (mm)}.$$

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It should be understood that the above-mentioned limit of the size of the tubular passages, the opening, the septum, and the case depends on the power requirement and that the power requirement will vary depending upon the electric device to be engaged with the cell pack 20.

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Another embodiment of the present invention is shown in FIGS. 4 and 5. As with the first embodiment, the battery pack 30 is suitable for continuous use while engaged by air-admitting needles. The metal-air battery includes a plurality of cells 10 enclosed within a cell case 32. The figures are exaggerated for illustration. The case 32 defines a cell pack 34 and isolates the plurality of cells 10 from the outside air with the exception of openings 36 that are covered with a self-sealable septum 38. The openings 36 on the bottom surface of the cell pack 34 are defined by grids 40 that may divide each cell 10 and be made of a case material. The grids 40 may mechanically support the septum 38. In this embodiment, there is a small reactant air plenum 42 in the cell pack 34. The septum 38 is affixed on the bottom surface of the cell pack 34 and terminates an air pathway to the outside air at the openings 36. The cell pack 34 therefore does not have any air vents on the cathode side of the separator between the air cathode and the electrolyte.

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A plenum case 44 defines an air plenum box 46 and has a plurality of hollow needles 48 and openings 50. The air plenum box 46 may be positioned and serve as an air collection plenum. The hollow needles 48 having sharp needle tips 52 and longitudinal tubular passages 54 are positioned on the upper surface of the air plenum box 46. Any number of needles at any place of the upper surface may be used to satisfy the power requirement. It is preferable to have one or more needles in each opening 36.

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As described in the first embodiment, the cells 10 are isolated from the outside air to have leakage current minimized and to have a long shelf life when

they are not used, inactive, or in the storage. The plenum box 46 engages with the cell pack so that the needle tips 52 pierce portions 56 of the septum 38 and that the needles 48 penetrate the septum 38 to provide air pathways to an air plenum 58 when the cell pack 34 is in use or the cells 10 are active. The total cross-sectional area of the tubular passages 54 are generally larger than that of the openings 50 so that the total air flow through the tubular passages 54 is larger than that through the openings 50. Therefore, right after the engagement, the current available from the cells 10 increases rapidly consuming a reactive gas, e.g. oxygen, in the plenum 58 and gradually decreases upon using up the stored oxygen. Finally the available current becomes constant and is determined by the air flow rate through the openings 50. Thus, the current characteristics satisfactory for an initial high power requirement of a connected electric device may be controlled by the total cross-sectional areas of the tubular passages 54 and the openings 50, and volume of the plenum 58.

If the steady current needs to be very low, the openings 50 are preferably sized such that their length, i.e., the direction through the thickness of the case 44 is greater than their width, i.e., the direction perpendicular to the thickness of the case 44 such that diffusion of air through the openings 50 may be substantially limited. By "substantially limited," it is meant that the rate of diffusion of oxygen or contaminants through the openings 50 is so slow that humidity transfer is sufficiently small and has little appreciable impact on the efficiency or lifetime of the cell 10 after the output current becomes almost constant.

As described in the first embodiment, the plenum box 46 may be disengaged from the cell pack 34 such that the needles 48 may be removed from the septum 38, which will reseal itself. Thus, the used cell pack may keep its residual power during a period of storage. Further, the septum 38 may be made of a semi-permeable material such that the initial open cell voltage will remain high enough after a long storage as mentioned above. The sizes, the number, and the materials of the case 32, the openings 36, the septum 38, the plenum box 46, the needles 48, their tubular passages 54, and the openings 50 may be preferably varied as

described in connection with the first embodiment. In particular, the needles 48 may preferably be shorter for handling without losing their functions.

5 In the first two embodiments, to protect the cells from flooding or drying out during times when no load is connected to the battery, the battery pack must be disengaged to reseal the septum. Another embodiment is shown in FIG. 6, which has the same cell pack 20 as shown in FIG. 1. This embodiment provides a battery pack that can remain engaged with needles through a septum without being subject to flooding or drying out. The features of the cell pack 20 are the same as described in connection with the first embodiment. However, it shows an air manager 60 with an air manager case 62, two needles 70, 72, a fan 80 as an air-
10 moving device, and two diffusion limiting tubes or isolation tubes 82, 84 connected to the outside air through a wall of the case 62.

The air manager is positioned such that the needles 70, 72 can penetrate the septum 16. The needles 70, 72 are hollow and their needle tips 86, 88
15 are sharp to pierce portions 90, 92 of the septum 16 as described in the first embodiment. The needles 70, 72 are positioned on the upper surface of the air manager case 62 such that the air manager may engage with the septum 16 under the cell pack 20. The air manager case 62 is essentially impermeable such that two tubular passages 94, 96 of the needles 70, 72 and the openings 82, 84 are the only
20 pathways to the outside of the case 62. The fan 80 is positioned in the case so as to divide space inside of the case 62 into two chambers 98, 100 and make an air flow and/or pressure difference in the case such that an outlet air flow from the cells through the tubular passage 94 and an inlet air flow to the cells through the tubular passage 96 may occur. Pressurization of the chamber 100 causes air to flow
25 through the tubular passage 96 and also out of the chamber 100 to the outside, through the tube 84. At the same time the low pressure created in the chamber 98 causes air to be drawn from the cells through the tubular passage 94, and make-up air is drawn into the chamber 98 from outside through the tube 82. The make-up air is then re-circulated between the air manager and the cells.

30 The sizes of the tubular passages 94, 96 are generally larger than those of the openings 82, 84 such that an air flow resistance of the tubular passages

94, 96 may be smaller than that of the openings 82, 84. Thus, more air generally moves through the tubular passages 94, 96 in the re-circulation process.

When the cell pack 20 is not engaged with the air manager, the cell case 12 and the septum 16 isolate the cells 10 such that the cells 10 have a long shelf life. When the cells 10 are in use or are active, the air manager 60 engages with the cell pack 20 with the needles 70, 72 penetrating the septum 16 to about halfway along their length. Thus, the tubular passages 94, 96 provide air pathways from the air cathodes (not shown) of the cells 10 to the chambers 98, 100 of the air manager 60. If the chambers 98, 100 are large and filled with a reactive gas and if the tubular passages 94, 96 are wide, the initial available current characteristics are similar to those described in connection with the second embodiment. Since the openings 82, 84 are diffusion limiting tubes, the cells 10 may have a long shelf life when the fan 80 is off, even when the septum remains pierced by the needles 70, 72. The tubular passages 94, 96 could alternatively be the diffusion limiting tubes in a way of isolating the cells 10.

The diffusion limiting tube may be referred to as an isolating passageway or a diffusion limiting passageway due to its isolating capability. In accordance with an example in US Patent 5,691,074, the diffusion limiting passageways function to limit the amount of oxygen that can reach air cathodes to minimize the self discharge and leakage or drain current of a metal-air cell.

The diffusion limiting passageways 82, 84 (or alternatively 94, 96) also minimize the detrimental impact of humidity on the metal-air cell, when the fan 80 is not forcing air flow through the diffusion limiting passageways 82, 84 (or alternatively 94, 96). A metal-air cell that is exposed to ambient air having a high humidity level may absorb too much water through its air electrode and fail due to a condition referred to as "flooding". Alternatively, a metal-air cell that is exposed to ambient air having a low humidity level may release too much water vapor from its electrolyte through the air electrode and fail due to a condition referred to as "drying out".

The efficiency of the isolating or diffusion limiting passageway in terms of the transfer of air and water into and out of a metal-air cell can be described

in terms of an "isolation ratio". The "isolation ratio" is the ratio of the rate of water loss or gain by a cell while its oxygen electrodes are fully exposed to the ambient air, as compared to the rate of the water loss or gain of the cell while its oxygen electrodes are isolated from the ambient air, except through one or more limited openings, that is, diffusion limiting passageways. For example, given identical metal-air cells having electrolyte solutions of approximately thirty-five percent (35%) KOH in water, an internal relative humidity of approximately fifty percent (50%), the ambient air having a relative humidity of approximately ten percent (10%), and no fan-forced circulation, the water loss from a cell having an oxygen electrode fully exposed to the ambient air should be more than 100 times greater than the water loss from a cell having an oxygen electrode that is isolated from the ambient air, except through one or more diffusion limiting passageways. In this example, an isolation ratio of more than 100 to 1 should be obtained.

More specifically, each of the diffusion limiting passageways 82, 84 (or alternatively 94, 96) preferably has a width that is generally perpendicular to the direction of flow therethrough, and a length that is generally parallel to the direction of flow therethrough. The length and the width are selected to substantially eliminate air flow and diffusion through the diffusion limiting passageways 82, 84 (or alternatively 94, 96) while the air moving device is not forcing air flow through the diffusion limiting passageways 82, 84 (or alternatively 94, 96). The length is greater than the width, and more preferably the length is greater than about twice the width. The use of larger ratios between length and width are preferred. Depending upon the nature of the metal-air cells, the ratio can be more than 200 to 1. However, the preferred ratio of length to width is about 10 to 1.

The isolating or diffusion limiting passageways 82, 84 (or alternatively 94, 96) could form a portion of the air path must take between the ambient and the oxygen electrodes. Each of the diffusion limiting passageways 82, 84 (or alternatively 94, 96) may be defined through the thickness of the case 62, but preferably they are in the form of tubes as described above.

In general, the diffusion limiting passageways may be cylindrical, and for some applications each can have a length of about 0.3 to 2.5 inches or

longer, with about 0.88 to 1.0 inches preferred, and an inside diameter of about 0.03 to 0.3 inches, with about 0.09 to 0.19 inches preferred. The total open area of each diffusion limiting passageway for such applications, measured perpendicular to the direction of flow therethrough, is therefore about 0.0007 to 0.5 square inches. In other applications, the diffusion limiting passageways each can have a length of about 0.1 to 0.3 inches or longer, with about 0.1 to 0.2 inches preferred, and an inside diameter of about 0.01 to 0.05 inches, with about 0.15 inches preferred. The preferred dimensions for a particular application will be related to the geometry of the passageways and the cathode plenums, the particular air mover utilized, and the volume of air needed to operate the cells as a desired level.

By way of example, in a preferred embodiment of a cell pack designed to power a portable computer (not shown), a 6-volt battery with 6 cells is used. Each cell has an output of about 1 volt or slightly higher at about 1 to 4 amps. Each cell has an exposed cathode area (not shown) of about 18 to 22 square inches for a total exposed cathode area of about 108 to 132 square inches. The battery therefore has a current density of about 50 to 200 ma per square inch of cathode surface. In order to satisfy this power requirement, an air flow from 33 to 200 cubic inch/min is needed.

The diffusion limiting passageways are not necessarily cylindrical, as any cross-sectional shape that provides the desired isolation is suitable. The isolating passageways need not be uniform along their length, so long as at least a portion of each diffusion limiting passageway is operative to provide the desired isolation. Further, the diffusion limiting passageways may be straight or curved along their length. In fact, a diffusion limiting passageway may be formed by a gap between spaced apart two-dimensional surfaces, so long as the air molecules must follow a sufficiently restricted path to move from the ambient air to the air cathode. Other exemplary diffusion limiting passageways and systems are disclosed in U.S. Patent No. 5,691,074 and U.S. Application No. 08/556,613, and the entire disclosure of each of those documents is incorporated herein by reference.

Referring again to FIG. 6, when the fan 80 is turned on, a relatively large amount of air flow comes from the outside of the air manager case 62 through

the opening 82, mixes with air flow coming through the tubular passage 94, and goes into the plenum 18 through the tubular passage 96 and out of the case 62 through the opening 84. Thus, the cell pack can supply a connected electric device with required power. The fan's rotational speed may be adjusted to supply the required power. The fan is operated with power from the cells 10, and is connected by leads and terminals not shown in FIG. 6.

Since the openings 82, 84 are diffusion limiting passageways, air flow through the passageways 82, 84 may be more quantitative. The passageways 82, 84 are, thereby, preferably constructed and arranged to allow a sufficient amount of air flow therethrough while the air moving device or the fan 80 is operating so that a sufficient output current, typically at least 50 ma, and preferably at least 130 ma can be obtained from the metal-air cells 10. In addition, the diffusion limiting passageways 82, 84 are preferably constructed to limit the air flow and diffusion therethrough such that the drain current that the metal-air cells are capable of providing to a load while the fan 80 is not forcing air flow through the passageways 82, 84 is smaller than the output current by a factor of about 50 or greater. Thus, when the fan 80 is off and the humidity level within the cell is relatively constant, only a very limited amount of air diffuses through the passageways. The water vapor within the cell protects the air cathodes (not shown) from exposure to oxygen. The air cathodes are sufficiently isolated from the ambient air by the water vapor such that the cells 10 have a long shelf life without sealing the passageways 82, 84 with mechanical air doors or the like. In addition, the diffusion limiting passageways 82, 84 are preferably constructed to provide the isolation ratio of more than 50 to 1.

When the air manager 60 is disengaged from the cell pack 20, the cells 10 are essentially isolated from the outside air, and the drain current can be as low as the storage modes before first use of the cell pack 20. With the help of the semi-permeable septum 16, an initial open cell voltage may be maintained. When the air manager 60 engages the cell pack 20, the openings 82, 84 may be the only air pathways to the outside air and the drain current mode with the fan off is reduced as described above. When the fan is turned on, the current to a load can be

varied between several modes adjusted by the fan speed control to satisfy the power requirement.

5 Since the air manager 60 may be reusable with other cell packs even after the cell pack 20 discharges its energy, it is possible to minimize disposable parts. The sizes, the number, and the materials of the case 12, the openings 14, the septum 16, the plenum 18, the air manager case 62, the needles 70,72, their tubular passages 94,96, the chambers 98, 100, the fan 80, and the openings 82, 84 may be preferably changed as described in connection with similar parts used in the earlier embodiments.

10 In particular, if the needles 70,72 are large such that their tubular passages 94,96 may be larger than the diffusion limiting tubes, the fan 80 may inhale more air flow from the outside. Thus, the air cathode is exposed to air including higher concentration of oxygen so that the battery may supply more energy when the fan 80 is on. On the other hand, when the fan 80 is off and the air
15 manager 60 engages with the cell pack 20, that is, when the battery is temporarily inactive, the cells are less isolated from the ambient air that may have a high or low humidity level so that the cells 10 are more likely to fail due to a condition referred to as "flooding" or "drying out" as described before. This may be prevented, if the air manager 60 is disengaged from the cell pack 20 such that the air passageways
20 are re-closed by the septum 16.

Another embodiment of a cell pack 110 according to the present invention is shown in FIG. 7. A cell pack case 112 encloses cells 10, a reactive air plenum (not shown), and an air manager portion including two chambers 114, 116 separated by a fan 118. An opening 120 connects the chambers 114, 116 to the
25 plenum. An opening 122 extends across both chambers 114, 116 and is covered with a septum 124 and sealed off from the outside air. The air manager is an air-moving device having the fan 118 to make air flow and/or pressure difference between two chambers 114 and 116. Two needles 126, 128 secured to a needle board 130 are positioned so as to puncture portions 132, 134 of the septum 124.
30 The needles 126, 128 have sharp needle tips 136, 138 and tubular passages 140, 142 as described in the other embodiments.

When the cells 10 are not in use or inactive, the needles 126, 128 are apart from the septum 124 and cell isolation is maximized as described above. If the septum 124 is made of a semi-permeable material, a satisfactory initial open cell voltage may be maintained during storage. When the cells 10 are in use or active, the needles 126, 128 penetrate the septum 124 at portions 132, 134 to provide air pathways from air cathodes (not shown) of the cells to the outside air. When the fan is turned on, the air is circulated with make-up fresh air through the tubular passages 140, 142 and the load current is adjusted by varying the fan speed to satisfy a high power requirement of a connected electric device.

If the cell pack must be well isolated when the fan is off, the tubular passages may be sized to be diffusion limiting isolation tubes as described above. When the needles 126, 128 are apart from the septum 124, the cells 10 are essentially isolated from the outside air and the drain current may be minimized to as low a mode as the storage modes existing before first use of the cell pack 110. With the help of the semi-permeable septum 124, an initial open cell voltage may be maintained. When the needles 126, 128 penetrate the septum 124 at portions 132, 134, the tubular passages 140, 142 may be the only air pathways to the outside air and the drain current mode with the fan off is reduced as described above. When the fan is turned on, the current to a load can be varied between several modes adjusted by the fan speed control to satisfy the power requirement.

In this embodiment, a small part such as the needle board 130 can start the cell pack so as to be a switch without any electrical contacts, and provide power to a battery-preinstalled electric device. The sizes, the number, and the materials of the case 112, the openings 120, 122, the septum 124, the plenum (not shown), the chambers 114, 116, the fan 118, the openings 120, 122, the needles 126, 128, their tubular passages 140, 142, and the board 130 may preferably be changed for the purposes described above.

Another embodiment is shown in FIG. 8, which includes a cell pack 150, and an air-managing head 152, mounted in an electric device 154. The cell pack 150 includes a case 156, cells 10, a reactive air plenum below the cells (not shown), and an extra plenum 158, adjacent to an opening 160 covered by a septum

162. A pair of terminals 164, 166 connected to positive and negative leads (not shown) from the cells 10 are positioned on the exterior of the case 156 facing the air-managing head 152. The case 156 isolates the cells from the outside air with the help of the septum 162 as described in the other embodiments. The extra plenum
5 158 may diffuse and mix fresh and residual air inside of the case 156 and supply each air cathode evenly with reactive gas, i.e., oxygen. In the alternative, the extra plenum may be omitted, in which case the needles are directed into the reactive air plenum. If the septum 162 is made of a semi-permeable material, an initial open cell voltage may be maintained during storage.

10 The air-managing head 152 includes a case 170, which defines an outwardly facing rectangular recess 172 for receiving the cell pack 150. Two engaging arms 174 with knobs 176 define the recess to receive and engage with a portion of the cell pack 150. Two recesses 178 on opposite exterior walls of the cell pack case 156 receive the knobs 176 with force caused by elastic bending of the
15 arms 174 in a similar way as a ratchet mechanism. Two terminals 180, 182 are positioned on a back wall of the recess 172 to engage the terminals 164, 166, respectively. Two electrical terminals 184, 186 or hard wiring are provided on the other side of the head 152 to supply the electric device 154 with electrical power from the cell pack 150.

20 Two chambers 188, 190 are formed in the air-managing head 152 separated by an air mover such as a fan 192. A needle 194 extends out from the chamber 188 and a needle 196 extends out from the chamber 190. The chambers 188, 190 are connected to outside air through tubes 198, 200, respectively. The tubes 198, 200 (shown diagrammatically) preferably are diffusion limiting isolation
25 tubes of the type described above, and the needles 194, 196 have larger openings 202, 204 designed for free air flow rather than isolation purposes.

Thus, the cell pack 150 is removably held by the air-managing head 152 coinciding with the needles 194, 196 penetrating the septum 162. The needles 194, 196 have sharp needle tips 206, 208 to pierce portions 210, 212 of the septum
30 162 and the tubular passages 202, 204 to provide air pathways between air cathodes (not shown) of the cells 10 and the two chambers 188, 190.

5 The fan 192 makes an air flow and/or pressure difference between two chambers 188 and 190, the fan 192 being disposed in-between. The openings 198, 200 communicate with the outside air or a reactive gas source such that the reactive gas, e.g., oxygen can come through one of the openings 198, 200 and one of the tubular passages or openings 202, 204 to reach the air cathodes of the cells 10, in a manner described above.

10 In this embodiment, the air-managing head 152 is installed in the electric device 154 such that the consumers need only buy the cell pack 150. The cell pack can be stored in completely sealed conditions with an impermeable septum 162 or an impermeable tape (not shown) can be affixed on a semi-permeable septum 162. In the latter case, retail stores may stock the cell pack 150 after removing the tape or consumers may remove the tape sometime before use, so that the cell pack has a satisfactory initial open cell voltage. The sizes, the number, and the materials of the case 156, the opening 160, the septum 162, the plenum (not shown), the extra plenum 158, the chambers 188, 190, the fan 192, the openings 15 198, 200, the needles 194, 196, their tubular passages 202, 204, and other parts may preferably be changed as described above.

20 Another embodiment is shown in FIGS. 9, 10, and 11. A cylindrical metal-air battery or power supply has an air-managing head 220 and a cell pack 222 like the embodiment shown in FIG. 6. The air-managing head 220 has a cylindrical coupling 224, an outer case 226, two openings 228, 230, and a positive terminal 232. The cell pack has a negative terminal 234, an outer case 236, and a coupling portion 238 with two positive terminals 240, two negative terminals 242, and an elongate self-sealable septum 244.

25 The air-managing head 220 further includes two positive terminals 246 disposed inside of the circular cylinder 224 opposite to each other, two negative terminals (not shown) disposed inside of the circular cylinder 224 in orthogonal positions to the positive terminals 246, two hollow needles 248, 250 parallel to the axial direction of the battery, two chambers 252, 254 divided by a fan 30 256, and a fan controller 258.

5 The two chambers 252, 254 are defined with a circular plate 260 and other walls, and formed in the air-managing head 220 separated by an air mover such as the fan 256. The needle 248 extends out from the chamber 252 and the needle 250 extends out from the chamber 254. The chambers 252, 254 are connected to outside air through openings 228, 230, respectively. The openings 228, 230 (shown diagrammatically) preferably are diffusion limiting isolation tubes of the type described above, and the needles 248, 250 have larger openings 262, 264 designed for free air flow rather than isolation purposes.

10 The cell pack 222 further includes two cells having anode gels 266, anode containers 268, air cathodes 270, insulating end plates 272, 274, 276, current collectors and leads 278, 280, and an air plenum 282. The end plate 276 has a slit opening covered with the elongate septum 244. The two negative terminals 242 are connected to the anode containers 268 with leads 280. The two positive terminals 240 are connected to current collectors (not shown) of the air cathodes 15 270 with leads (not shown). These four terminals are positioned on the exterior circular periphery of the coupling portion 238 so as to connect to corresponding terminals inside of the cylindrical coupling 224 of the air-managing head 220 in order to supply the fan 256 with electric power. The positive terminal 232 of the power supply is also connected to the terminals 246 with leads (not shown). The fan controller 258 also is connected to control the supply of electric current from the 20 cell pack 222 to the fan 256. If the elongate septum 244 is made of a semi-permeable material, a satisfactory initial open cell voltage may be maintained during storage.

25 The cell pack 222 may be removably held by the air-managing head 220 coinciding with the needles 248, 250 penetrating the elongate septum 244. To selectively lock the cell pack 222 to the head 220, a connector (not shown) may be provided, such as the knobs and recesses of the previous embodiment. The needles 248, 250 have sharp needle tips 284, 286 to pierce portions 288, 290 of the septum 244, and the tubular passages 262, 264 provide air pathways from air cathodes 270 30 of the cells to the two chambers 252, 254.

5 The fan 256 makes an air flow and/or pressure difference between two chambers 252 and 254. The openings 228, 230 communicate with the outside air such that oxygen can come through one of the openings 228, 230 and one of the tubular passages 262, 264 to reach the air cathodes 270 of the cells, in a manner described above.

10 In this embodiment, the air-managing head 220 is separable for re-use such that the consumers need only buy the cell pack 222. The cell pack can be stored in completely sealed conditions with an impermeable septum 244 or an impermeable tape (not shown) can be affixed on a semi-permeable septum 244. In the latter case, retail stores may stock the cell pack 222 after removing the tape or consumers may remove the tape sometime before use, so that the cell pack has a satisfactory initial open cell voltage. The sizes, the number, and the materials of the case 236, the septum 244, the plenum 282, the chambers 252, 254, the fan 256, the openings 228, 230, the needles 248, 250, their tubular passages 262, 264, and other parts may preferably be changed as described above. In particular, the cylindrical coupling 224 may be formed in the same size as the outer case 226 such that the whole battery is formed in a regular battery size such as "AA".

20 The above description is that of preferred embodiments of the invention. Various alterations and changes can be made without departing from the spirit and broader aspects of the invention as set forth in the appended claims, which are to be interpreted in accordance with the principles of patent law, including the Doctrine of Equivalents.

Claims

What is claimed is:

- 5 1. A metal-air power supply system comprising:
 an enclosure surrounding one or more metal-air cells each
including an air electrode;
 a structure providing a first air pathway segment within the
enclosure from the air electrode to a puncturable, resealable septum comprising at
10 least a portion of the enclosure surrounding said cell;
 a hollow needle forming a portion of a second air pathway
segment connected to a source of reactive gas and positioned such that said needle
is capable of puncturing the septum.
- 15 2. The metal-air power supply system of claim 1 further
comprising at least one diffusion limiting passageway in said second air pathway
segment.
- 20 3. The metal-air power supply system of claim 2 wherein said
diffusion limiting passageway is defined by said needle.
4. The metal-air power supply system of claim 2 further
comprising at least one air-moving device in said air pathway.
- 25 5. The metal-air power supply system of claim 4 wherein said
air-moving device is disposed between said needle and said diffusion limiting
passageway.